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The Role of Shift Work And Fatigue in Air Traffic Control Operational Errors and Incidents

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16. Abstract

This report was developed from a collaborative effort between the FAA Civil Aeromedical Institute's (CAMI's) Shift Work and Fatigue Research Program and the National Aeronautics and Space Administration (NASA) Ames Research Center's Fatigue Countermeasures Program. The purpose of this report was to examine existing databases to assess the extent to which shift work and fatigue might be factors associated with incidents and errors in air traffic control (ATC) operations. The first study in this report examined the Aviation Safety Reporting System (ASRS) database, a voluntary reporting system administered and maintained by NASA. The ASRS database was searched for reports concerning ATC incidents. Of the 5773 ATC reports in the database, a search of 19 fatigue-related keywords identified 153 (2.7%) reports referencing controller-related fatigue in the narrative section of the ASRS incident report. These reports spanned the years from 1988 to 1996. These reports were categorized by year of occurrence, aircraft type, fatigue category, incident type, time of day, day of the week, and lighting condition. Controller fatigue was the most commonly identified category in the 153 fatigue-related reports, followed by workload and duty or scheduling factors. Fatigue was reported as a performance-impairing factor affecting personnel at all times of the day, in all types of operations, and manifested itself in a variety of anomalies in ATC operations. The second study in this report examined the Operational Error/Deviation System (OEDS) database, a mandatory reporting system managed and operated by the FAA. A total of 3222 records was examined. These reports spanned the years from 1988 to 1994. The analyses in this study included: 1) descriptive statistics for shift work-related variables, 2) correlations between shift work variables and severity of OEDs, and 3) Chi-square analyses of causal factors and shift type. Frequency counts revealed that 80% of OEDs occurred between 0800 and 1900 and nearly 50% of errors occurred within the first 30 minutes on position, usually upon returning from a break. None of the shift work variables was a strong predictor of the severity of operational errors. Data-posting types of errors were more likely on the midnight shift, possibly reflecting declines in alertness and vigilance on that shift. Unfortunately, many of the variables related to shift schedules and fatigue were unable to support much analysis because of data quality problems and confounding with air traffic volume. To adequately assess the changes in OED rates as they relate to time of day, an estimate of exposure is needed.

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PREFACE

THE ROLE OF SHIFT WORK AND FATIGUE IN AIR TRAFFIC CONTROL OPERATIONAL ERRORS AND INCIDENTS

Pamela S. Della Rocco, Ph.D.

The shift schedules worked by Air Traffic Control Specialists (ATCS) in the Federal Aviation Administration (FAA) have been the focus of research off and on since the early 1970s (Melton, McKenzie, Smith, Polis, Higgins, Hoffmann, Funkhouser, Saldivar, 1973). In recent years, concerns have been raised from the research community about the association between the documented effects of shift work, such as sleep loss, circadian disruption, and subsequent sleepiness on the job, and increased risks of errors, incidents, and accidents in job performance (Mitler, Dinges, and Dement, 1994). While research on ATCSs has documented patterns of shortened sleep associated with shift schedules (Saldivar, 1977; Cruz and Della Rocco, 1995), the extent to which these patterns may result in increased incidents has not been systematically examined.

The current technical report was developed from a collaborative effort between the National Aeronautics and Space Administration (NASA) Ames Research Center's Fatigue Countermeasures Program and the FAA's Civil Aeromedical Research Institute's (CAMI's) shift work and fatigue research program. The idea originated from a planning meeting designed to identify potential areas for collaborative ATCS shift work research. The goal of each program has been to develop effective fatigue countermeasures in aviation-related operational settings. The meeting resulted in the identification of seven important areas of research: 1) assessment of the extent of fatigue in ATCS operations; 2) survey of ATCS personnel for schedule and issues related to coping with shift work; 3) education and training for alertness management and shift work coping strategies; 4) fatigue countermeasures as they relate to the ATCS work environment; 5) aging workforce issues; 6) acute and cumulative sleep loss effects; and 7) individual differences. This report addressed the first area of research by examining existing databases to assess the extent to which fatigue might be manifest in terms of incidents and errors.

There were two existing sources for information on errors and incidents: 1) The Aviation Safety Reporting System (ASRS), and the 2) Operational Error/Deviation System (OEDS). The ASRS is a voluntary incident reporting system established in 1975 under a Memorandum of Agreement between the FAA and NASA. Administered by NASA, the system is used by pilots, ATCS, mechanics, flight attendants, and others involved in or observing a situation in which aviation safety was compromised. Confidentiality for the reporter is assured to facilitate reporting. Information has been successfully used to remedy problems and improve the National Airspace System, as well as provide a resource for research into aviation-related human factors. The OEDS is a mandatory reporting system for FAA Air Traffic Control facilities. It is used as a management resource tool for improving air traffic operations. The purpose of this report was to examine these existing data sets for evidence of shift work-related fatigue to estimate the degree to which fatigue may have been a problem.

Because the data sources were very different in terms of purpose and data collection (i.e., voluntary vs. mandatory reporting), the analyses supported by each database were different. The format of this technical report, therefore, maintained the independent analyses of the two different databases and combined two separate reports under a single cover. As with all research involving databases designed for purposes other than the research at hand, caution must be used in the interpretation of the findings. Each database is very useful for its intended purpose. However, the data have important limitations when used for empirical research. Specifically, errors and accidents generally have a number of contributing causes and are frequently the result of low probability events occurring together. The effects of fatigue and sleep loss also are subject to individual differences and involve both work-related and nonwork-related factors. With the appropriate cautions in mind, these reports examined the existing databases to determine if there was evidence of possible systematic influences and assessed the degree to which these data support such analyses with the goal of improving the utility of the data in the future.

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INTRODUCTION

Modern society requires 24-hour operations to meet many demands. These demands occur in many different environments: transportation, healthcare, manufacturing, military, communications, and many others. It is estimated that about 18% of full-time U.S. workers are involved in shift work (U.S. Department of Labor Statistics, 1993). This work group is involved in regular night work (about 56% of shift workers), irregular night work (about 22%), and rotating shifts (about 22%). An extensive collection of scientific literature demonstrates that shift work, especially night work, is associated with an increased occurrence of errors, incidents, and accidents (Akerstedt, 1995; Dinges, 1995; Rosa, 1995). Shiftwork can result in both sleep loss and circadian disruption, and these physiological factors have been linked to sleepiness on the job and subsequent performance decrements (Akerstedt, 1994; Dinges, 1989; Folkard and Monk, 1985; Mitler, Dinges, and Dement, 1994).

Night work involves disruption of two major physiological factors: sleep and the circadian clock. Working at night requires wakefulness during the period when physiological programming dictates sleep. Conversely, sleep is undertaken during the day when physiological programming dictates wakefulness. The day sleep of shift workers has been documented to be significantly shorter, up to 2-4 hours less, compared with usual nighttime sleep (Akerstedt, Kecklund, and Knutsson, 1991). With an acute sleep loss and cumulative sleep debt, the night worker is predisposed to sleepiness that is compounded by the 3-5 AM circadian trough.

Survey studies have demonstrated that, while day workers report no or only marginal sleepiness, a significant majority of night shift workers do report sleepiness on the job (Paley and Tepas, 1994). These studies have determined that about 10-20% of workers report regularly falling asleep during night shifts (Akerstedt, Torsvall, and Froberg, 1983; Akerstedt and Torsvall, 1985). These reports of sleepiness have also been documented physiologically in work environments. For example, physiological sleepiness has been measured in train drivers (Torsvall and Akerstedt, 1987) and pilots flying long-haul, transpacific schedules (Rosekind, Graeber, Dinges, Connell, Roundtree, Spinweber, and Gillen, 1994).

Shiftwork scheduling can encompass a variety of approaches that includes altering the direction of shift rotations (clockwise vs. counterclockwise), rapid vs. slow rotations, differing start times and duration of time between rotations. Each of these approaches has different effects on the physiological factors. For example, a clockwise shift rotation involves a phase delay that is in synchrony with the normal circadian pattern. However, a counterclockwise rotation involves a phase advance that is contrary to the usual pattern of the circadian clock. A rapid rotation schedule does not attempt to shift or adapt the circadian pattern, while a slow rotation intends to facilitate some adaptation to an altered circadian schedule. Start time effects can include early report times for a day shift that still interrupt sleep and create an acute or potentially cumulative sleep debt, or earlier (advancing) start times that differ from a previous day. The time between shifts affects the amount of time available for recovery sleep prior to initiating a new

round of shifts. The time is usually too short for circadian readaptation but can allow some recovery sleep prior to the next shift.

There also can be important non-physiological reasons why shift workers choose some types of rotations over others. For example, in some work environments, there is a differential in pay for night work, or workers can alter their schedules with shift opportunities to obtain increased shift length or compressed work weeks that permit maximal time off.

These shift work issues apply directly to the requirements of maintaining essential 24-hour air traffic control (ATC) operations. In a programmatic line of previous research, the FAA Civil Aeromedical Institute (CAMI) has examined the commonly used "2-2-1" ATC schedule, the "2-1-2" schedule, and 10- vs. 8-hour shift lengths (Della Rocco, Cruz, and Schroeder, 1995). The "2-2-1" schedule involves a counterclockwise rotation of two afternoon shifts, then two morning shifts, and a night shift (Della Rocco and Cruz, 1995). The "turn around" time between shifts can be as short as 8 hours. The "2-1-2" schedule involves two afternoon shifts, then a mid-day shift, and then two morning shifts (Cruz and Della Rocco, 1995). The 10- vs. 8-hour shift length study examined the effects on performance and alertness (Schroeder, Rosa, and Witt, 1995).

The extensive scientific literature on the physiological effects of shift work and the specific CAMI research on the ATC environment, demonstrate the need for greater understanding of the physiological, behavioral, and environmental effects of shift work on ATC alertness and performance. This information will provide the scientific foundation for countermeasures that promote optimal ATC performance and alertness during shift work.

Therefore, to further examine these issues relative to the ATC environment, the CAMI researchers, in collaboration with the NASA Ames Fatigue Countermeasures Program, developed a joint plan for a program of activities to address fatigue issues in ATC operations. Seven activity areas were identified and are listed in the Preface of this document, with an important first step of determining the extent of fatigue in Air Traffic Control Specialists (ATCS). Two initial projects were undertaken that capitalized on existing databases regarding errors and incidents related to ATCS operations. The CAMI group examined the Operational Error/Deviation System database, while the NASA group examined the Aviation Safety Reporting System (ASRS) database. The following reports the findings from the ASRS analysis.

METHODS

The NASA Aviation Safety Reporting System database contains voluntary reports of incidents that occur in the National Airspace System provided by any involved individual. These incident reports are anonymous, confidential, and associated with a limited immunity. The database provides an unique opportunity to examine errors and incidents reported from the operators in the aviation system. ASRS points out that there are limitations to the interpretation and generalizability of the database. Therefore, ASRS can establish that an incident occurred, provide information surrounding the occurrence, and allow for some types of analyses. However, it cannot be used to establish the base rate of incidents or as representation of the only occurrences, outcomes, or responses to errors in aviation operations. The database is comprised of specifics of the occurrence that include a narrative of the incident. A search of the database can examine particular types of information or use key words to pull out reports relevant to the question under study.

A previous study by Lyman and Orlady (1981) examined pilot-reported incidents related to fatigue (19). In that study, specific keywords were used to search for fatigue-related incident reports and the reports were then analyzed for type of incident and other factors.

As a first step to examine fatigue issues relative to the ATC environment, keyword searches of the ASRS database were undertaken based initially on the Lyman and Orlady study (19). The ASRS database was searched for reports concerning air traffic control incidents.

There were two searches that used a total of 19 fatigue-related keywords to examine their occurrence in the ASRS incident reports. The first search was based on the seven specific keywords employed in the Lyman and Orlady (19) study and included the following:

FATIGUE	WORKLOAD
SLEEP	DUTY/SCHEDULING
TIME OF DAY	COMPLACENCY
TIRED	

It should be noted that these keyword searches account for variations of terms such that similar word references, like *sleepy* or *asleep*, would also be found by the search program. A second search was undertaken with the following 12 keywords:

LETHARGIC	INATTENTION
PERFORMANCE	LOW ENERGY
FIXATED	POOR COMMUNICATION
FORGETFUL	APATHETIC
HARDLY AWAKE	NOD OFF
EXHAUSTED	INADEQUATE REST

The searches were conducted from a sample of 56,589 full-form incident reports submitted to ASRS since January 1988. Overall, ATC-related reports to ASRS represented 5,773 incidents (approximately 10.2%) of the total searched. From these 5,773 ATC reports, 171 (3%) were identified with the keywords and referenced controller fatigue in the narrative section of the ASRS incident report. These reports represented a timeframe of February 1988 through March 1996.

The 171 reports were reviewed by Fatigue Countermeasures Program researchers to determine that the reports referenced human fatigue and did not refer to non-related topics. Of the 171 reports received from ASRS, 153 were determined to be related to human fatigue and were analyzed further. The report narratives were examined and classified into the different fatigue categories reported here.

RESULTS

There were 153 individual ATC fatigue-related incident reports that represent 2.7% of the total 5,773 controller reports in the ASRS sample used. These 153 reports represent individual incidents, though some involved reporting by multiple sources. However, these are considered as one incident with multiple inputs. The reports included 110 (72%) submitted by controllers, 57 (37%) from flight crew members, and 1 from an observer.

Based on the specific ASRS sample used for this search, Figure 1 displays the distribution of these fatigue-related ATC incident reports received by ASRS annually from 1988 through 1996.

The incident reports represented a wide range of aircraft types. Though the sample was predominantly in the transport category, small aircraft and military aircraft reports were also present. Figure 2 displays the types of aircraft represented in the analyzed sample.

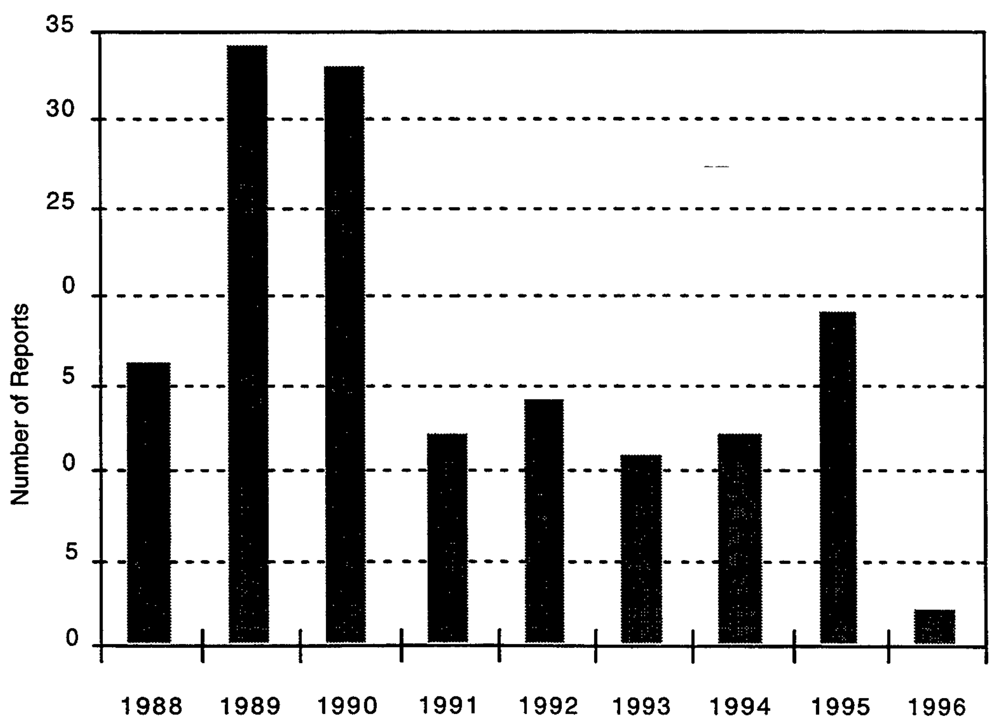

Figure 1. Distribution of annual ASRS fatigue-related incident reports since 1988

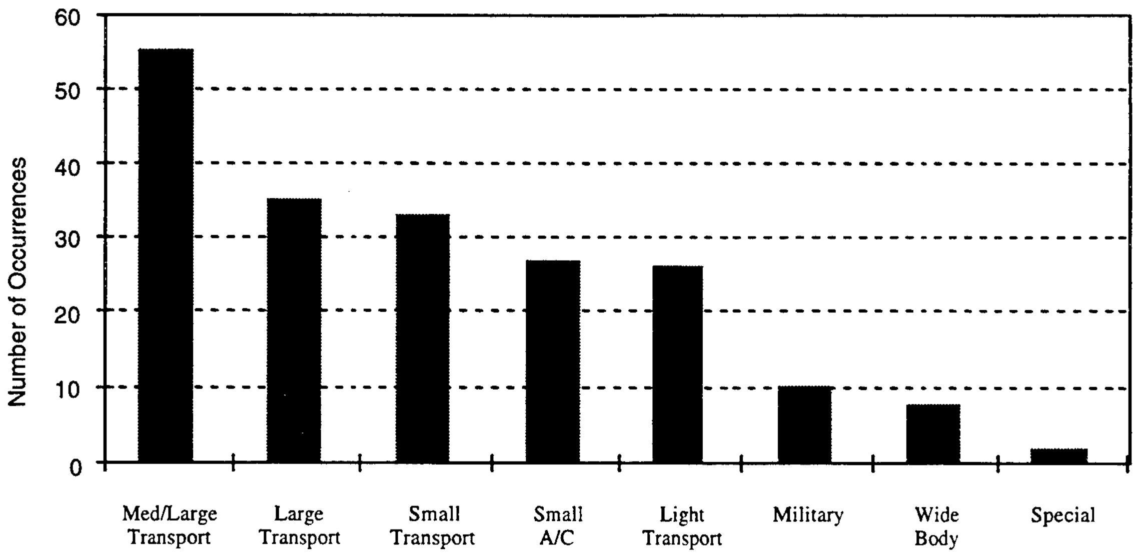

Figure 2. Aircraft types reported in ASRS incident reports

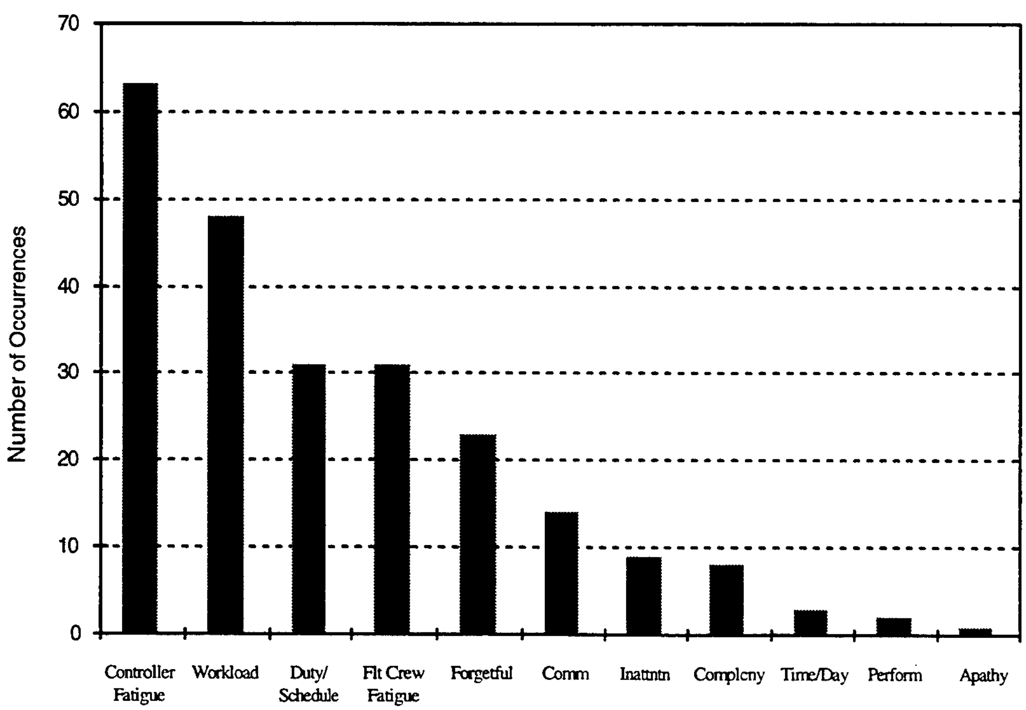

Figure 3. Fatigue categories found in ASRS incident reports

The sample of ATC fatigue-related incident reports was classified into the following categories: controller fatigue, workload, duty/schedule, forgetfulness, inattention, complacency, performance, and apathy. In addition, these categories were also used which were not specific to controllers alone: flight crew fatigue, communications, and time of day. Figure 3 displays the distribution of reports into these categories. The category with the highest number of reports was controller fatigue, followed by workload, equal numbers for duty/schedule and flight crew fatigue, and then forgetfulness and communications. The remaining categories had fewer than 10 reports, with apathy represented by a single incident report.

The incident anomalies were then categorized according to operations. The types of operational incidents and anomalies that occurred in relation to these reports of fatigue are portrayed in Figure 4. The most often reported anomaly was "less than legal separation," which represented 37.6% of the sample. The most often cited "other" category was facility staffing problems. Reported anomalies also included altitude deviations, track/heading deviations, airspeed error, airborne conflict, and runway transgressions.

Reports were examined for their occurrence during different times of the day. ASRS reports are deidentified with the specific time of the incident to ensure confidentiality; however, they are categorized for quarter of the day. Time categories are based on local time at the facility where the incident occurred. Figure 5 portrays the distribution of reports over the quarters of the day, as used by ASRS analysts. For the sample used, the highest number of reports occurred within daytime operating hours, with 36.2% during the afternoon. The remaining incidents were distributed with 30.9% reported in the morning, 25% during the evening, and 7.9% during the night. Some report narratives referenced times of day, with 11 related to night operations, 7 reported working the mid (or midnight) shift , and 2 indicated early morning shift starts.

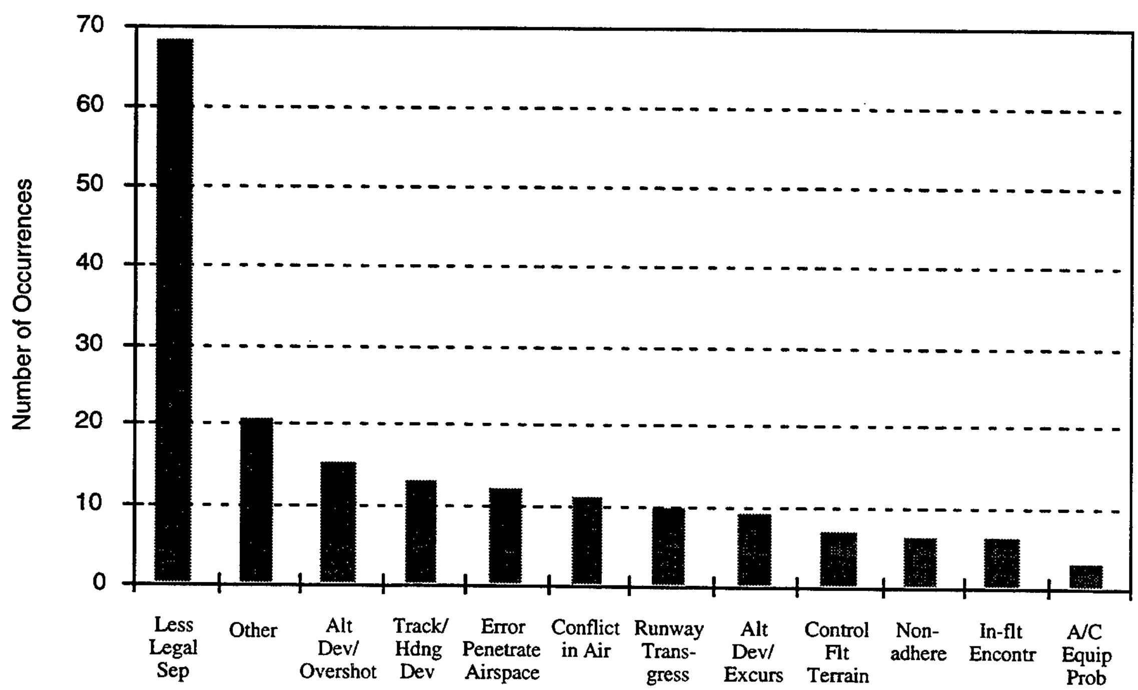

Figure 4. Anomaly descriptions categorized from ASRS incident reports

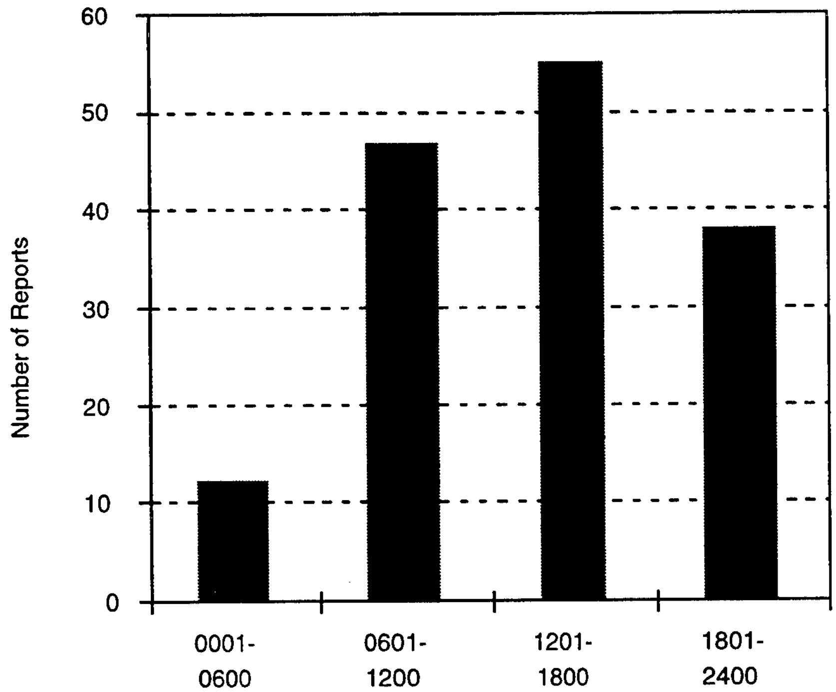

Figure 5. Distribution of ASRS incident reports across quarters of the day.

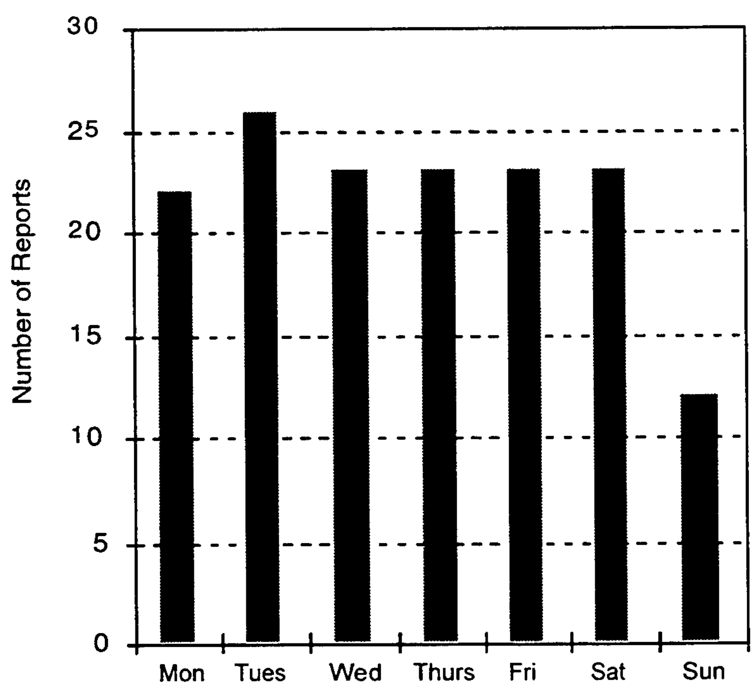

Figure 6. Distribution of ASRS incident reports over days of the week

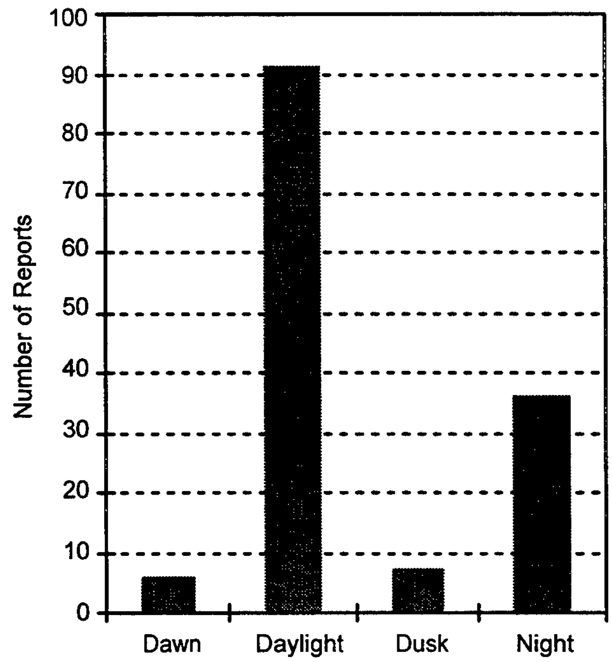

Figure 7. Lighting conditions for ASRS incident reports

Figure 6 displays the distribution of reports over the days of the week. The pattern demonstrates a relatively uniform reporting of fatigue-related incidents during the week.

The sample also was analyzed for lighting condition by time of day. The reports were categorized by lighting conditions and separated into quarters of the day as previously described. The results are displayed in Figure 7. Information about lighting conditions was included in 140 of the 153 reports. Most of the incidents, about 65%, occurred during "daylight" conditions, followed by 25.7% during "night," 4.3% occurred during "dawn," and 5% during "dusk."

DISCUSSION

The ASRS database provided a unique opportunity to examine errors and incidents reported from operators within the aviation system. However, there were limitations to the interpretation and generalizability of the data.

Following a search with fatigue-related keywords and examination of the identified incidents, 153 reports were determined to be related to human fatigue. These reports represented the full range of operational conditions, though most involved transport operations. The most common anomaly reported was "less than legal separation." Other reported anomalies included such events as altitude/ heading deviations, airborne conflicts, and ground-based (i.e. runway) transgressions.

Controller fatigue was the most commonly identified fatigue category (which adds face validity to the search), followed by workload and duty or scheduling factors. High workload levels, staffing shortages, and problems with shifting schedules were also cited by reporters as contributing factors.

Most reports occurred during the 1201 to 1800 afternoon window of time. Almost two-thirds of the reports occurred during daylight conditions. While these findings may be related to the higher level of traffic during daytime operations, it is clear that fatigue-related incident reports are not limited to late night or shift work operations. Reports also were distributed evenly across the days of the week, with the fewest incidents occurring on Sundays.

Despite the limitations of the reports examined from the ASRS database, it was apparent that fatigue was reported as a performance-impairing factor affecting personnel at all times of the day, in all types of operations, and manifested itself in a variety of anomalies in ATC operations. These preliminary findings support the need for further investigation into how sleep and circadian factors affect controller performance, as previously outlined in the Preface and in "other considerations" (below).

A next step would be a more detailed study of ATC schedules to specifically examine the effects of fatigue, sleep loss and circadian variables, and their effects on performance in ATC operations. The implementation of education and training activities, as well as proven fatigue countermeasures, could provide near-term benefits to ATC operators. These issues are especially challenging in the context of the complex ATC environment that include an aging workforce, the effects of acute and cumulative sleep loss, and individual differences. It will be important to identify appropriate control and comparison groups to properly interpret the results of any future ATC fatigue-related study.

The scientific findings from a variety of other shift environments clearly demonstrate that fatigue, sleep loss, and circadian disruption can affect performance and alertness during operations. A continued, proactive program that translates proven fatigue counter-

measure approaches into operational use in the ATC environment and pursues research into relevant areas has tremendous potential benefits for aviation safety.

OTHER CONSIDERATIONS

As outlined in the Preface, other areas that could be addressed to fully understand the extent of fatigue in ATC operations include: examining ATC schedules and personnel, education and training, fatigue countermeasures, aging workforce issues, acute and cumulative sleep loss effects, and individual differences.

An examination of ATC schedules and personnel should focus on two components: 1) ATC schedules and shift-related factors and 2) an ATC personnel shift work survey. The first activity would involve a survey of schedules that would examine at least the following information: schedule variations (hours of shifts, combinations), seasonal variations (vacations, annual leave, sick leave), swapping (credit hours taken, overtime, shift pay differential), schedule stability/variability over time, recovery (time off between rotations), decision factors (seniority, center, facility), on call and reserve status, schedule procedures (advanced publishing), and patterns of leave usage. Some of these data can be accessed through published schedules and FAA databases. Demographics of interest would include sex, age, length of service, time at facility, and technical experience.

The second activity would involve accessing a large, representative sample of ATC personnel from a range of operations. A survey of this workforce would be conducted to examine at least the following factors: demographics, sleep (quantity, quality, night vs. day), circadian factors, lifestyle (diet, mood, performance), schedule experience, preference, swaps, overtime, compression, workload, signs and symptoms of fatigue in the workplace, countermeasure strategies (alcohol, medication, naps, caffeine), health (stomach problems, physical activity), individual differences (morningness/eveningness, adjustment ratings, sleep), job satisfaction, identify previous strategies or scheduling approaches or alternative ideas, breaks and break activity, caffeine use, and exercise patterns. These activities would examine fatigue, sleep, and circadian variables in ATC operations, the perception of their effect on performance, and coping strategies.

The NASA Ames Fatigue Countermeasures Program has developed and successfully implemented an education and training module on alertness management in flight operations (Rosekind, Gander, Connell, and Co, in preparation). The CAMI researchers have a parallel module in development with initial field tests for the ATC environment. This activity would involve further and final development of an education and training module for alertness management in ATC operations. An implementation plan would be developed to determine who delivers the module, where it is provided, the forum for presentation, what materials are provided to ATC operators (and trainers), other support for distribution and use of the information. Another important component of this activity involves an evaluation of the module. This would include assessing knowledge acquisition, including retention over time, and application of information from module to actual practice, and perceived efficacy. As an ongoing activity, there would be specific programs for maintaining the knowledge base, reinforcement of the material, and continued visibility for the education and training module. As required, the module and implementation program would be updated to keep it state-of-the-art and relevant.

A range of fatigue countermeasures already established as effective in the laboratory should be examined for their potential translation to field implementation. Possible countermeasures include napping, bright light, melatonin, and schedule design. A study of schedule alternatives and specific comparisons could be conducted in the controlled environment of the laboratory. Melatonin is a natural hormone produced by the pineal gland that is under investigation for its use as a sleep aid and for its chronobiotic effects. Melatonin could be examined for its efficacy in promoting sleep prior to a midshift or as an adjunct to a napping strategy. Bright light has been investigated for its chronobiotic effects of shifting the internal circadian clock and for its alerting effects. A study examining the ability of bright light to increase ATC alertness during night shifts would present interesting challenges regarding displays and night vision. CAMI has initiated an activity to examine the applicability of napping strategies in the ATC environment. There is a variety of other strategies that also could be systematically examined for their

effectiveness, such as the timing of breaks, physical activity, strategic caffeine use, and melatonin and relaxation skills for promoting daytime sleep.

The other considerations previously identified also deserve attention. There are numerous issues related to an aging workforce, especially as it relates to fatigue factors such as the effects of sleep loss and circadian adaptation. Recovery from acute and cumulative sleep loss in an operational setting is a crucial topic for understanding the long-term effects and vulnerability associated with a lifetime of shift work. The ability for short and long-term recovery (in sleep and for the circadian clock) on different shift schedules has not been systematically examined. There are many important issues related to individual differences that require investigation. This is a significant arena that has minimal data with obviously relevant considerations to the ATC operations setting. These issues range from good vs. bad adapters to age effects to other individual factors that could account for performance and alertness effects in ATC operations. An important consideration will be to identify appropriate control and comparison groups to interpret the results of any particular project.

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OPERATIONAL ERRORS/DEVIATIONS AND SHIFT WORK IN AIR TRAFFIC CONTROL

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INTRODUCTION

Since 1990, the Human Factors Research Laboratory of the Civil Aeromedical Institute (CAMI) has investigated issues related to specific shift schedules worked by Federal Aviation Administration (FAA) Air Traffic Control Specialists (ATCSs). The present study was designed to complement previous research and examine the extent to which specific shift schedules might interact with operational errors/deviations (OEDs). An OED occurs when an ATCS fails to maintain applicable separation minimums between aircraft (or between aircraft and obstructions or specified airspace). An operational error (OE) involves loss of separation between an aircraft and another aircraft or obstruction. An operational deviation (OD) involves an aircraft under the control of the causal ATCS that enters airspace controlled by someone other than the causal ATCS (e.g., another ATCS or the military) (Rogers and Nye, 1993).

ATCSs in many air traffic control (ATC) facilities work a variety of counterclockwise, rapidly rotating shift schedules (Della Rocco and Cruz, 1995). One specific implementation of this type schedule is termed the "2-2-1" because it involves working two afternoon shifts, followed by two morning shifts, and finally, a night shift within a five-day period. Other versions of counterclockwise rotations worked in ATC facilities have been described elsewhere (Cruz and Della Rocco, 1995; Schroeder, Rosa, and Witt, 1995). Some variations include midnight shifts and some do not. Early morning shifts are a frequent characteristic of many ATCS schedules. In fact, some ATCSs work as many as four to five early morning shifts within a five-day schedule.

Data from both laboratory and field studies have suggested a pattern of decreasing sleep durations over the course of the 2-2-1 work week and shortened sleep durations on any early morning shift (either within a counterclockwise rotation or on four or five straight early morning shifts) (Saldivar, Hoffman, and Melton, 1977; Schroeder, Rosa, and Witt, 1995; Della Rocco and Cruz, 1995; Cruz and Della Rocco, 1995). Similar findings have been reported in the European and military literature (Folkard, 1989; Luna, French, Neville, Mitcha, Storm, 1994). In a laboratory study of the 2-2-1 (Della Rocco and Cruz, 1996), the hypothesis was tested that the sleep loss during the course of the week, in combination with the circadian trough during a midnight shift at the end of the week, would result in performance decrements on complex task battery performance. The findings revealed performance decrements of about 8-12% only on the midnight shift and suggested that the complex task performance was fairly robust. Schroeder, Rosa, and Witt (1995) reported decreased reaction times on performance of cognitive tasks on the midnight shift with ATCSs working 2-2-1 schedules. Midnight shift performance of U.S. Air Force (USAF) controllers working clockwise rotating shift schedules was not found to differ from day and swing-shift data; however, the authors reported a tendency for impaired task learning on the midnight shift (Luna et al., 1994).

From the previous research and literature, it could be hypothesized that the loss of sleep over the course of the work week, especially after early morning shifts would result in sleepiness, both day and nighttime, and might be related to increased operational errors occurring later in the work week, specifically on the midnight shift.

Since 1985, the FAA has collected information on OEDs in the Operational Error/Deviation System (OEDS) (Rogers and Nye, 1993). The OEDS is a database managed and operated by the National Aviation Safety Data Center Division of the FAA's Office of Aviation Safety. In 1987, the data collection form was modified to include documentation of the shift schedule of the ATCS identified as a causal factor in the OED. This addition was designed to make it possible to assess the relationship between aspects of work schedules and OEDs. Previous reports from this database had exam-

ined the association between OEDs and workload conditions with data from 1985-1987, as well as the factors associated with the severity of OEs at Air Route Traffic Control Centers with data from 1988-1991 (Rogers and Nye, 1993; Schroeder and Nye, 1993).

The initial purpose of the present report was to examine the FAA's OEDS database to assess the relationship between OEDs and aspects of the shift schedules worked by ATCSs. However, the entire week's shift schedule was not entered in the final data set. In addition, it was not possible to test the hypothesis that errors would be relatively higher on the midnight shift due to sleep loss or the circadian trough because of the lack of an estimate of exposure. Because traffic levels are substantially lower in most facilities—but not all—on the midnight shift, exposure rates are different between shifts, as well as among facilities. No adequate estimates of traffic levels by time of day for the time period were reasonably available.

Therefore, this report presents information from the database that best addresses the issues of shift work and OEDs, as well as documents the weaknesses in the existing data with the goal of improving data quality in the future. Several variables were selected to provide some insight into the possible relationship between shift work and OEDs. Three sets of analyses were conducted. Specifically, descriptive data for shift work-related variables (e.g., time of occurrence, time on position, day of work week), the extent to which these factors were correlated with the OED severity and the controller's awareness of the development of the OED, and the relationship between contributing causal factors and shifts were presented.

METHOD

Operational Error/Deviation System (OEDS)

The OEDS is a microcomputer-based database designed to track the operational errors and deviations across the national air traffic control (ATC) system. Upon the occurrence of an OED, the Quality Assurance personnel at each facility collect information about the incident and complete a standard form as prescribed in FAA Order 7210.3 Facility Operation and Administration. Data are then coded and entered into the OEDS database. A copy of the database was provided to the Civil Aeromedical Institute for research analyses. The most current data set at the time of these analyses included data from 1988 to March 1994.

Upon arrival at CAMI, the data set was "cleaned up," such that only records with a valid year (year > 0) and a valid time of occurrence, as well as the ATCS identified as a causal factor, were selected. In addition, for purposes of this report, only OEDs for Air Route Traffic Control Centers (ARTCC) and Terminal Radar Approach Control (TRACON) facilities were selected. Thus, incidents from towers and flight service stations were not included. Finally, the database is maintained in three files: a master file, an employee file, and an aircraft file. The master file included information about the incident, such as the facility, incident severity, flight conditions, and traffic conditions. The employee file included information such as the employment background, demographics, and shift-related data. The aircraft file included information such as the aircraft type, onboard equipment, and flight plan. For this report, the master and employee files were matched into one file to obtain one record for each incident. If an incident was recorded in one of the original two files and not the other, the incident was dropped from the data set reported here. Likewise, if the data set contained duplicate records, one of them was purged. Finally, cases with any missing values for the variables investigated, with the exception of the severity variable, were excluded from the analyses. The severity variable was coded only for the ARTCC OEDs and was missing in the TRACON data. The final set contained 3,222 records.

Approach

Data fields related to shift work and OED causal factors were selected from the data dictionary for analyses. Initial data quality cross-checks were conducted to examine 1) the degree to which fields were populated, and 2) the extent to which information in selected fields agreed with other appropriate fields. Thus, frequencies were examined for each variable and then cross tabulations were examined, as appropriate, to determine the consistency of the information. The specific variable list included the following data fields:

Table 1
Description of Variables.

VARIABLE	DESCRIPTION
Time of Occurrence (local)	Time the incident occurred in local time.
Time of Occurrence (GMT)	Time the incident occurred in Greenwich Mean Time.
Shift	Shift employee was working when the incident occurred.
Hour of Occurrence	Number of hours into the employee's shift when the incident occurred.
Day of Work Week	Number of days into the employee's work week when the incident occurred.
Time on Position	Indicator of how long the employee was on the current position worked at the time of the incident from the last non-control activity or a change of position.
Last Non-control Activity	Indicator of the employee's last non-control activity, such as breaks.
Time Since Last Non-control Activity	Time since the last activity not involving air traffic control; not including pre-briefing.
Type of Last Day Off	Indicator of the type of last day off taken by the employee.
Severity	Indicator of the severity of the incident based upon a point system of separation.
Awareness	Indicator of whether the employee was aware the incident was occurring.
Employee Causal Factors	Indicator of causal factors contributing to the incident. Up to eight contributing factors may be listed for each employee. There were six categories of factors: *Data Posting, Radar Display, Aircraft Observation (Towers only--not used in this report), Communications, Coordination, Position Relief Briefing.*

Data Quality

Because the initial purpose of this report was to examine the shift data, data quality checks were initiated with the shift field. A crosstabulation with local time was conducted. Table 2 presents the frequencies of OEDs by shift and time of occurrence in local time. Unfortunately, the criteria for coding shifts were not available from the Data Dictionary, nor readily from the Office of Aviation Safety because of new personnel and changes in the current forms. Examination of the shift variable by time revealed apparent errors in coding the shift. For example, OEDs occurring between 0000 and 0400 likely should not have been coded as day or evening shifts; but 11 operational errors were, in fact, reported as such. A cursory estimate of out-of-range shift values assuming liberal definitions of shifts could be postulated. If a day shift was defined between 0500-1959; an evening shift defined as 1000-2359; and a midnight shift defined as 2100-0859, then 9, 10, and 20 OEDs in each respective category would be questionable. This would represent a discrepancy rate of 1.2% of the 3,222 errors with shift information. While this appears small, the majority of questionable codes was during hours of the midnight shift and represented 28% of the 72 OEDs coded as midnight shift incidents.

To examine whether or not these inconsistencies were due to problems with data in the local time of occurrence field or the shift variable, two cross-checks were conducted. The first check was to compute local time of occurrence from the data in the field containing time of occurrence in Greenwich Mean Time and compare the results with the data from the local time of occurrence field in the database. This resulted in a discrepancy rate of 1%. Discrepancies appeared to be caused by typographical errors. The second check was to examine the shift variable by time of day (local time) by hour into shift.

Table 2
Frequencies of Operational Errors by Shift and Time of Day

	SHIFT			
TIME OF DAY	Day	Evening	Midnight	TIME
0000-0059	2	3	9	**14**
0100-0159	2	1	3	**6**
0200-0259	1	2	5	**8**
0300-0359	0	0	2	**2**
0400-0459	2	0	5	**7**
0500-0559	3	1	2	**6**
0600-0659	35	0	6	**41**
0700-0759	166	0	0	**166**
0800-0859	211	3	0	**214**
0900-0959	255	0	0	**255**
1000-1059	232	2	0	**234**
1100-1159	221	2	0	**223**
1200-1259	205	6	0	**211**
1300-1359	171	31	0	**202**
1400-1459	126	123	1	**250**
1500-1559	51	197	2	**250**
1600-1659	30	256	2	**288**
1700-1759	20	209	5	**234**
1800-1859	7	201	3	**211**
1900-1959	5	148	4	**157**
2000-2059	1	123	3	**127**
2100-2159	1	59	2	**62**
2200-2259	0	32	7	**39**
2300-2359	0	4	11	**15**
SHIFT TOTALS	**1,747**	**1,403**	**72**	**3,222**

This check revealed discrepancies similar to those presented in Table 2. A possible reason for the miscoding on the midnight shift may be that a common term for a traditional evening shift among ATCSs is a "night" shift, and the traditional night shift is commonly termed a "mid." Because of the discrepancies with the midnight shift data, the shift variable was not used.

Computation of a New Shift Variable

For purposes of these analyses, it was possible to compute a new shift variable using two variables from the database: time of occurrence (local) and hour into shift. Four mutually exclusive shift types were defined, based upon previous observations of shifts worked in field facilities (Cruz and Della Rocco, 1995): Day Shift, Midday Shift, Evening Shift, and Midnight Shift were computed with start times beginning from 0500-0959, 1000-1259, 1300-2059, and 2100-0459, respectively. Definitions were designed to cover all possible combinations of time of occurrence and hour into shift. For example, an operational error that occurred at 0600 and 8 hours into the shift, would be defined as occurring on a midnight shift. Appendix A presents the computation of each shift, as defined with the times of occurrence and hours into shift.

Analyses

The CAMI data set was maintained and analyzed in SPSSx on the VAX mainframe. Three sets of analyses are presented here as follows: 1) descriptive data for the shift work-related variables (i.e., time of occurrence, day of work week, hour into shift, time on position, and type of last non-control activity); 2) correlations between shift work variables and awareness

and severity of OEDs occurring in ARTCCs only, and 3) Chi-square analyses and odds ratios for types of employee causal factors by the recomputed shift type.

Despite the fact the shift variable in the database was unreliable, we selected several other variables to provide some insight into shift work-related issues of fatigue. These data are presented in the descriptive analyses. It was expected that fatigue would increase with increasing hours into the shift, days into the work week, time on position, and time since last non-control activity.

The severity of an OED is categorized for ARTCCs based upon the closest proximity of an aircraft to another aircraft, airspace, or obstruction (Rogers and Nye, 1993). OEDs are categorized as major, moderate, or minor, as determined by a point system allocated to the separation distances both vertically and horizontally. A total of 752 OEDs was classified in an "other" category and not rated by the severity point system. These, as well as three OEDs with missing values, were excluded from the analyses. Thus, of the 2,518 OEDs occurring in ARTCCs, 1,763 were used in the analyses. To determine the extent to which the shift work variables predicted the severity of an incident, Spearman correlations were computed. It was hypothesized that the severity of the OED would increase with increasing values of the work schedule variables. For purposes of the correlations, severity was coded as follows: minor=1, moderate=2, and major=3.

The final analyses examined the relationship between the types of employee causal factors reported by type of shift for both ARTCCs and TRACONs. "Shift" was the recomputed variable (Appendix A) based upon local hour of occurrence and hour into shift. A total of 84 employee causal factors was identified and these were grouped into six categories. One type, Aircraft Observation Factors, applied only to Towers, and was therefore not considered here. Up to eight causal factors could be listed for each OED in the database. Therefore, each OED could have more than one causal factor with no differentiation of importance to the incident. A frequency count of each of the five categories was computed across all incidents. Therefore, the number of incidents counted for each category was not independent or mutually exclusive, but rather, each incident may have been counted once for each of the five causal factor categories. Chi-squares were computed to examine whether or not the types of causal factors were independent of shift. Odds ratios were calculated for significant Chi-square outcomes to investigate the odds that a particular factor occurred on a midnight shift, as compared with the odds that it occurred on one of the other shifts. The odds ratio measure was used to examine differences in the percentages of types of factors on each shift. An odds ratio of 1 indicates that the odds were equal. Confidence intervals were then computed for the odds ratios. If the 95% confidence interval for the odds ratio contains 1.0, this suggests that no relationship exists between exposure to the midnight shift and the presence of a particular employee causal factor.

RESULTS

Descriptive Data

Two facility types were represented in the database: Air Route Traffic Control Centers (ARTCC), which represented 78.2% (2,518) of the 3,222 operational errors, and Terminal Radar Control (TRACON) facilities, which represented 21.8% (704).

Table 3 presents descriptive data from the OEDS characterizing employee's normal work week and length of work days as follows:

Most ATCSs work five days per week and eight hours per day. Of the 3,222 operational errors, 2,912 (90.4%) reports indicated a normal work week of five days, and 3,023 (93.8%) reported a normal workday of eight hours. Alternative work schedules may have

Table 3
Number of Days Per Work Week and Number of Hours Per Workday Reported for the Normal Work Schedule

Number of Days	Frequency (%)
1	1 (<1%)
2	4 (<1%)
3	24 (<1%)
4	180 (5.6%)
5	2,912 (90.4%)
6	101 (3.1%)
Number of Hours	**Frequency (%)**
4	1 (<1%)
5	1 (<1%)
6	2 (<1%)
8	3,023 (93.8%)
9	117 (3.6%)
10	78 (2.4%)

accounted for four-day weeks and nine to ten-hour days. As with the shift variable, these data suggest that coding errors or nuances exist in these data fields.

Figure 1 presents frequencies of operational errors by time of day (local). Eighty percent of the operational errors were reported to have occurred between 0800 and 1900. The peaks at 0800 and 1600 may relate to the particularly high traffic levels in the morning and afternoon.

Figures 2 and 3 present frequencies of operational errors by the day of the employee work week and the hour into the shift, respectively. In a typical work schedule, such as the 2-2-1, the first four days of the work week are generally evening, midday, or day shifts. The fifth day is a midnight shift when traffic and, subsequently, error rates are lower. This may account for the decline in operational errors on the fifth day of the work week. The substantial declines

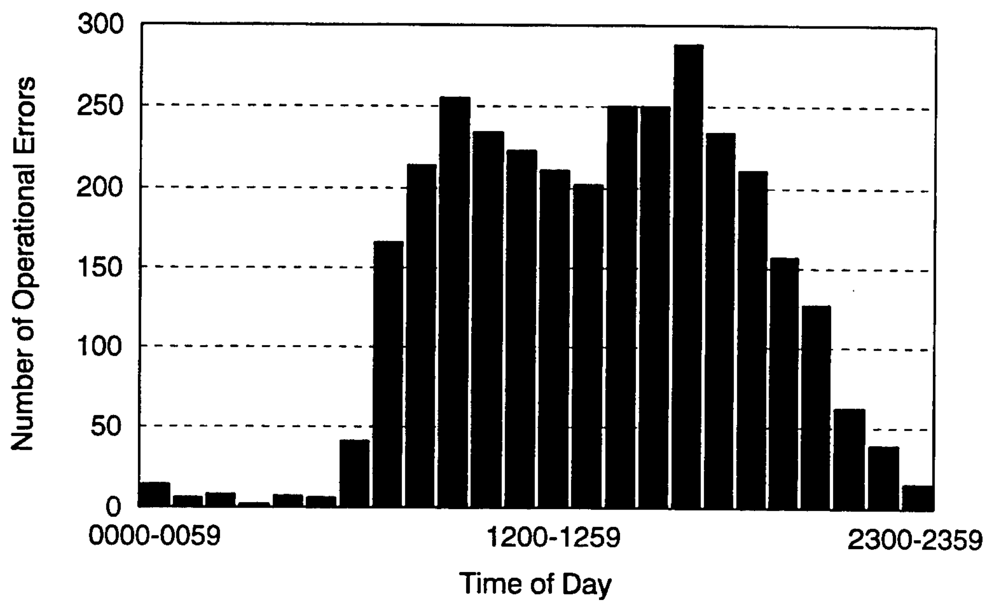

Figure 1. Operational Errors* by Time of Day, 1988 -1994.

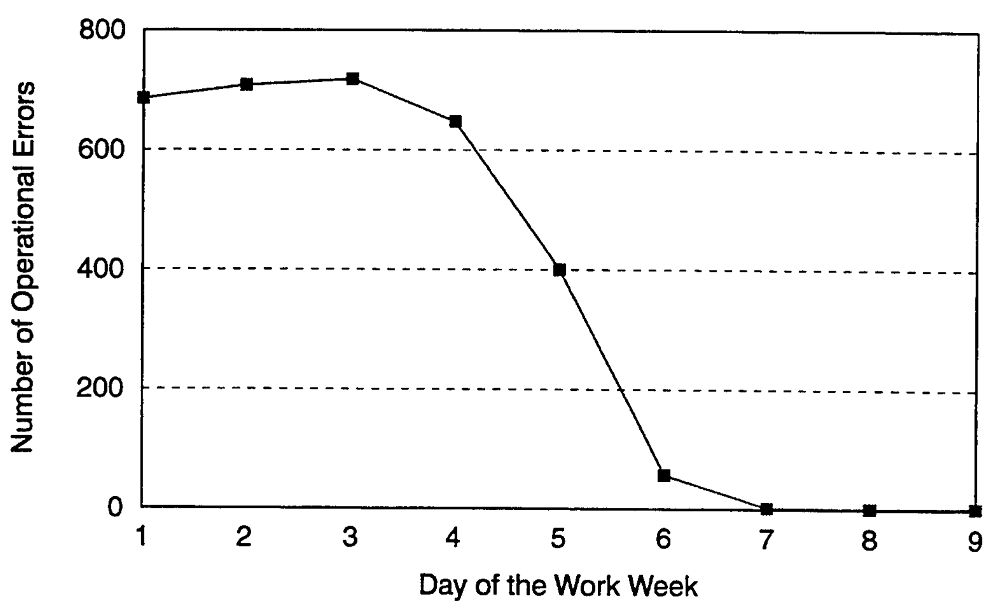

Figure 2. Operational Errors by Day of the Employee Work Week, 1988-1994.

seen on days 6 through 9 reflect the fact that ATCSs rarely work more than five days in a work week. OEDs appeared to be higher during the first half of the shift and declined during the last half.

Figure 4 presents frequencies of operational errors by time on position, or the amount of time a controller was actually working traffic. Errors were highest within the first 15 minutes on position and declined as time on position increased. Nearly half (46%) of the operational errors in this database were reported to have occurred within the first 30 minutes on position.

Figure 5 presents data for the type of last non-control activity prior to the OED. The highest percentage of errors (47.0%) occurred when the ATCS returned from a break.

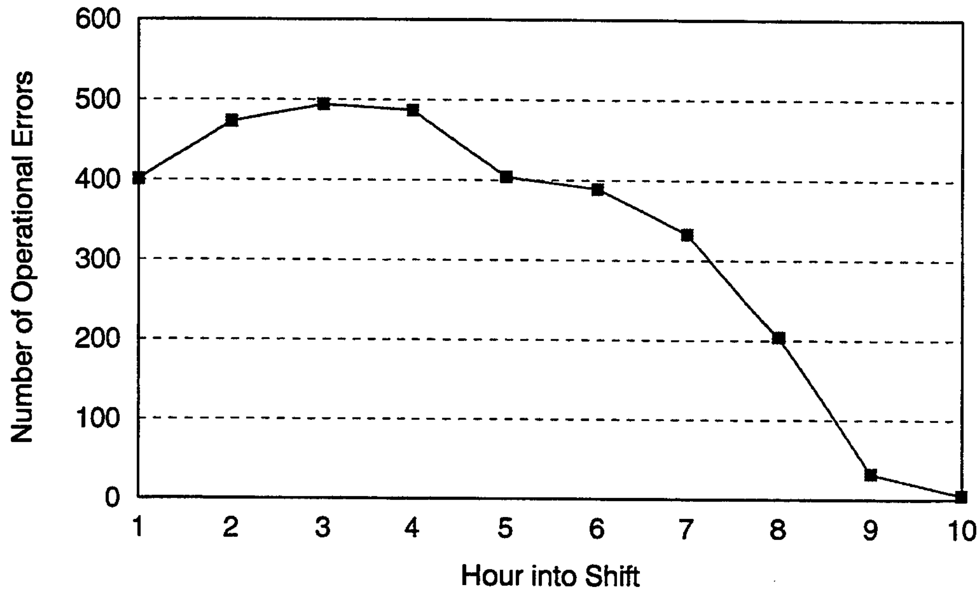

Figure 3. Operational Errors by Hour into the Shift, 1988-1994.

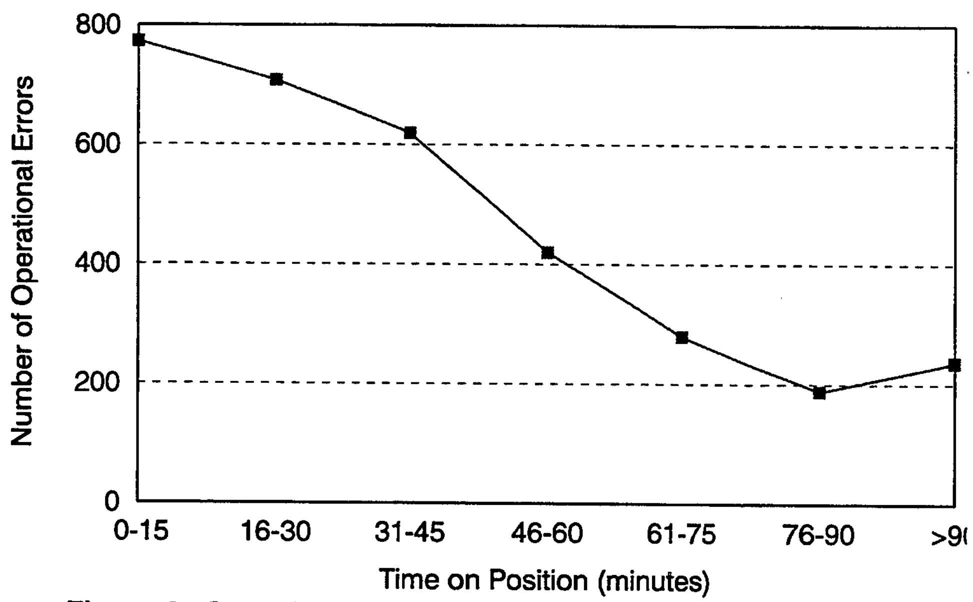

Figure 4. Operational Errors by the Amount of Time on Position, 1988 -1994.

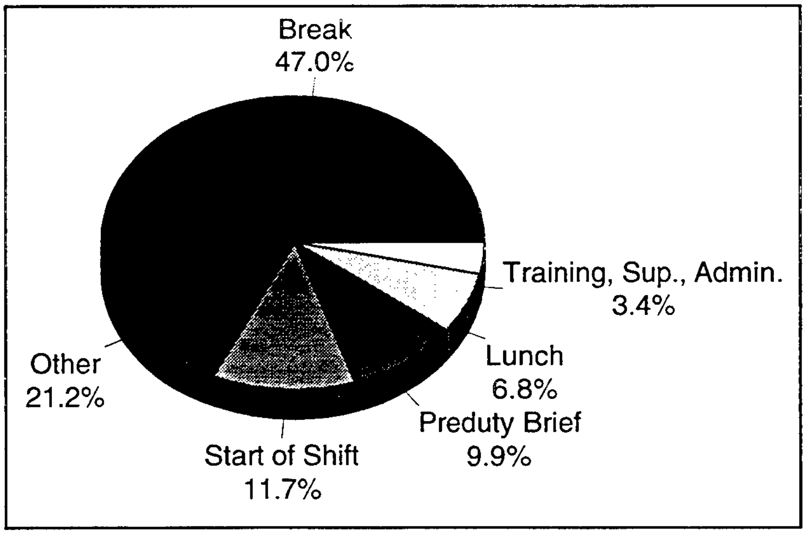

Figure 5. Percentages of the Type of Last Non-Control Activity Before an Operational Error.

The type of last day off was a variable in the database that indicated what kind of day off the last day taken off before the operational error was. The last day off for the vast majority of ATCSs (2,954; 91.7%) was a regular day off (RDO). The rest included sick leave (128; 4.0%), annual leave (123; 3.8%), and holidays (17; 0.5).

Relationship of Shift Work Variables to Severity and Awareness for ARTCCs.

These analyses examined the degree to which shift work variables were related to the severity of the OED and whether or not the ATCS was aware that an OED was developing. Table 4 presents the severity of OEDs for ARTCCs. Because severity of errors was only rated for the OEDs occurring in ARTCCs (n=1,763), the TRACON data were not included in this analysis. Ninety-nine percent of all OEDs were rated as moderate or minor in severity.

Table 5 presents descriptive data for the awareness variable, an indicator of whether or not the ATCS was aware that the incident was occurring. There were 1001 records in which data were coded as "yes" or "no." The table presents the number of records in which the ATCS reported being aware that it was developing.

Table 4. Severity of ARTCC OEDs.

	Number	Percent
Major	16	0.9%
Moderate	439	24.9%
Minor	1,308	74.2%
Total	**1,763**	**100%**

Table 5. ATCS Awareness of the Development of an ARTCC OED by Severity.

	Number Aware	Percent	Total
Major	0	0%	6
Moderate	74	34.3%	216
Minor	403	51.7%	403
Total	**477**	**47.7%**	**100%**

Table 6. Correlations between Shift Work Variables and Severity of Errors/Deviations and Awareness for ARTCCs.

Shift Work Variables	Severity	Awareness
Day of week	.029	-.040
Hour into shift	-.026	.011
Time on position	.043*	.002
Time since non-control	.033	.002
* p<.05		

Table 7. Analysis of Contributing Causal Factors for Operational Errors/Deviations by Shift.

		Proportion of Errors Committed by Shift			
CONTRIBUTING FACTOR	χ^2	Midnight	Day	Midday	Evening
Data Posting	27.9**	37.1%	19.5%	16.0%	15.1%
Radar Display	38.3**	32.9%	46.3%	52.8%	56.3%
Communication	15.6*	17.1%	30.8%	21.2%	27.5%
Coordination	14.4*	41.4%	40.6%	37.2%	33.9%
Relief Briefing	3.7	10.0%	5.0%	4.8%	4.9%

* p<.05
**p<.001

Table 8. Odds Ratios and Confidence Intervals for OED Employee Causal Factors.

	Odds Ratios & 95% Confidence Intervals		
	Midnight vs. Day	Midnight vs. Midday	Midnight vs. Evening
Data Posting	2.4 (1.5 - 4.0)	3.1 (1.7 - 5.6)	3.3 (2.0 - 5.5)
Radar Display	0.6 (0.3 - 0.9)	0.4 (0.2 - 0.8)	0.4 (0.2 - 0.6)
Communication	0.5 (0.2 - 0.9)	0.8 (0.4 - 1.5)	0.6 (0.3 - 1.0)
Coordination	1.0 (0.6 - 1.7)	1.2 (0.7 - 2.0)	1.4 (0.8 - 2.2)

Table 6 presents Spearman correlations between shift work variables and the severity of the OED and awareness.

A small but significant correlation was found between the time on position and the severity of the OED. The significant correlation would suggest that there is a small relationship between the time on position and the severity of the OED, such that the more severe errors occur with longer time on position. The other shift work variables failed to correlate with the OED severity or awareness.

Types of Employee Causal Factors by Shift Type

Within each of the five contributing employee causal factor categories, the percentages of the total 3,222 OEDS in both ARTCCs and TRACONs were as follows: data posting factors (17.8%), radar display factors (50.7%), communications errors (28.4%), coordination factors (37.6%), and relief briefing deficiencies (5.1%). Chi-square analyses were conducted to determine if type of causal factor was independent of shift. Results are displayed in Table 7. Chi-square analysis suggested that relief briefing factors were independent of shift.

Odds ratios and confidence intervals for significant chi-square results were calculated comparing proportions of employee causal factors on the midnight shift to each of the other shifts in Table 8. Data posting factors were 2.4, 3.1, and 3.3 times more likely to be reported as a contributing factor to the OED on the midnight shift than the day, midday, and evening shifts, respectively. Radar display factors were less likely to occur on the midnight shift than the day (0.6 times), midday (0.4 times), and evening shift (0.4 times). Communication factors were less likely to occur on the midnight shift than the day shift (0.5 times). Confidence intervals for the odds ratios indicated that communication factors were equally likely on the midnight shift as on the midday or evening shifts and that coordination errors were equally likely on the midnight shift as on the day, midday, and evening shifts.

DISCUSSION

The Operational Errors/Deviations System is an important management information system designed to track OEDs nationally in order to identify and manage safety trends. For those intended purposes, it serves the FAA well.

From these data, patterns of OEDs as they relate to time of day and some shift-related items could be characterized. Specifically, 80% of OEDs occurred between 0800 and 1900, a time when traffic levels are high across the system. In addition, nearly 50% of the errors occurred within the first 30 minutes on position. Examination of the last non-control activity revealed that this was usually after controllers returned from a break. Across the course of the work week, OEDs appeared to drop on day 5. As noted, however, the schedules worked by ATCSs confound the interpretation of these data. In addition, because traffic levels drop so precipitously on the midnight shift in most facilities, comparisons across shifts are confounded. None of the shift work variables were strong predictors of the severity of operational errors, although a significant but small correlation was found with time on position. It would, thus, appear that the indicators which might be vulnerable to shift work-related fatigue did not reveal the predicted increases in OEDs. As with many accident or incident databases, the sources of variability may be too great within the data to differentiate the contributing effects of factors such as fatigue unless the effects are quite robust.

After computing a new variable for shift, we were able to examine the types of employee causal factors and their comparative likelihood of occurrence across shifts. This comparison revealed that data posting factors were more likely on the midnight shift. Data Posting codes included factors such as problems with computer entry and flight progress strip management. In contrast, radar errors were less likely on the midnight shift. Radar display factors included items such as misidentification or overlapping data blocks. Because traffic levels are much lower on the midnight shift, it is reasonable that radar errors would be lower. However, the data posting types of errors could reflect declines in alertness and vigilance associated with the circadian trough and sleep loss on the midnight shift. It is possible that countermeasures to increase vigilance would assist in decreasing these errors.

Unfortunately, the variables that were designed to document the shift schedules and that might have shed light on the relationship between shift work and OEDs were unable to support much analysis. As with many other databases, those fields that are not regularly used in standard, periodic reports are vulnerable to poor data quality. The problems included data reliability and variables confounded by events (such as schedules) that were not documented well enough in the database. Data entry standardization and data quality checks would benefit future research. The information on shift schedules added in 1987 included shift work history for the previous week. This information is critical to understanding the relationship between shift schedules and risk for errors. Investigators should continue to collect the information as accurately as possible. Finally, to assess adequately the changes in OED rates as they relate to time of day, an estimate of exposure is required. Specifically, annual hourly traffic counts, reported nationally, would have been helpful for assessing risk.

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APPENDIX A

Computation of New Shift Variable

DAY SHIFT		MIDDAY SHIFT		EVENING SHIFT		MIDNIGHT SHIFT	
Time of Day	Hour into Shift	Time of Day	Hour into Shift	Time of Day	Hour into Shift	Time of Day	Hour into Shift
0500-0559	1	1000-1059	1	1300-1359	1	2100-2159	1
0600-0659	1-2	1100-1159	1-2	1400-1459	1-2	2200-2259	1-2
0700-0759	1-3	1200-1259	1-3	1500-1559	1-3	2300-2359	1-3
0800-0859	1-4	1300-1359	2-4	1600-1659	1-4	0000-0059	1-4
0900-0959	1-5	1400-1459	3-5	1700-1759	1-5	0100-0159	1-5
1000-1059	2-6	1500-1559	4-6	1800-1859	1-6	0200-0259	1-6
1100-1159	3-7	1600-1659	5-7	1900-1959	1-7	0300-0359	1-7
1200-1259	4-8	1700-1759	6-8	2000-2059	1-8	0400-0459	1-8
1300-1359	5-9	1800-1859	7-9	2100-2159	2-9	0500-0559	2-9
1400-1459	6-10	1900-1959	8-10	2200-2259	3-10	0600-0659	3-10
1500-1559	7-10	2000-2059	9-10	2300-2359	4-10	0700-0759	4-10
1600-1659	8-10	2100-2159	10	0000-0059	5-10	0800-0859	5-10
1700-1759	9-10			0100-0159	6-10	0900-0959	6-10
1800-1859	10			0200-0259	7-10	1000-1059	7-10
				0300-0359	8-10	1100-1159	8-10
				0400-0459	9-10	1200-1259	9-10
				0500-0559	10	1300-1359	10